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Photoluminescence studies of InAs/InSb nanostructures grown by MBE

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Semiconductor heterostructures based on narrow gap III–V compounds and their alloys are under intensive study as highly promising materials for mid-IR optoelectronic devices. InSb nanostructures are of peculiar interest having the narrowest band gap among these materials. During the past few years considerable success was achieved in the technology of InSb nanostructures embedded in different matrices. In particular, a thin layer of InSb was formed on GaAs substrates by MBE and optimal growth conditions were found for the formation of the nanometer-scale dots [1]. Photoluminescence (PL) of these objects has been studied in Ref. [2]. MBE growth of InSb embedded in GaSb was studied in [3], demonstrating a maximum red shift of an InSb quantum dot (QD) related PL peak to 1.7 μm for the InSb critical thickness of 1.7 monolayer (ML). Finally, self-assembled InSb QDs in GaSb, grown by metalorganic vapor phase deposition, were reported in Ref. [4]. However, until recently there have been no publications devoted to InSb/InAs nanostructures, although this system is of great interest, owing to its potential ability to emit or detect light in the spectral range 3–5 μm.

In this paper we report on the first MBE growth of InSb submonolayer insertions in an InAs matrix and PL studies of this heterostructure. The active region of the sample grown for PL studies consists of a 0.2 μm InAs layer centered with a 0.5 ML InSb insertion. The buffer structure involving a 0.5 μm InAs layer followed by a 20 nm thick AlSb barrier was grown at a substrate temperature $T = 480^{\circ}$C on an n-InAs substrate having an electron concentration $n \sim 2 \times 10^{16}$ cm^{-3}. The active region was grown at $T = 420^{\circ}$C. The existence of an optimum temperature ($T \sim 400^{\circ}$C) for MBE growth of GaInSb/GaSb strained quantum wells (QWs) has recently been proved by PL studies [5]. Degradation of optical properties was observed, either due to the formation of Sb clusters at lower temperatures, or due to structural defects arising from the enhanced group V molecule reevaporation from the surface at higher temperatures [6]. One should stress especially that the main problem here is intermixing of group V elements at the interfaces. Since we used conventional solid sources for As and Sb, the growth rate of the InSb/InAs active region was chosen five times lower as compared to that of the InAs buffer layer, with respective reduction of the As flux intensity [7], which allowed us to suppress the As incorporation into the InSb insertion.

The band alignment of the InAs/InSb heterostructure is predicted to be type-II broken gap [8]. In particular, the estimated valence-band offset for the strained InSb layer on InAs ΔE_v equals to 910 meV. The respective band diagram of the InAs/InSb/InAs active region is shown in Fig. 1. Note that due to 7% lattice mismatch between InSb and InAs either the formation of QW or self-organized growth of QDs can take place, depending on the amount of evaporated InSb. It will be shown further that the InSb submonolayer in our sample can be most probably regarded as a QW.

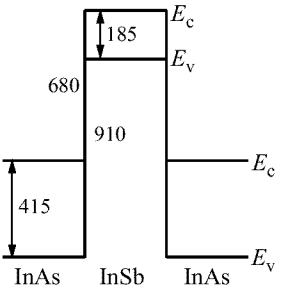

Fig. 1. Band alignment scheme for a InSb/InAs heterostructure of a strained InSb layer inserted into InAs. Energies are in meV. Only the highest valence state is shown.

PL measurements of the structure were performed in the temperature range from 2 to 102 K using for excitation an Ar^+ laser operating at 514.5 nm. The excitation power varied from 50 to 300 mW and the laser spot size was about 2 mm. A Bomem DA8 Fourier transform spectrometer equipped with an InSb detector was used for registration of PL spectra.

A relatively narrow PL peak (FWHM $\sim$ 20 meV) is observed at an energy less than the InAs band gap (see Figs. 2, 3). The PL maximum shifts towards higher energies with increasing excitation density (Fig. 2), whereas the temperature rise up to 102 K causes mainly a decrease of PL intensity (Fig. 3). The observed blue shift of the PL maximum with increasing excitation density is inherent for type-II structures and results from the dipole layer formation caused by spatial separation of non-equilibrium holes confined in the InSb layer and electrons confined in a triangular QW in the nearby InAs region [9]. The fact that the energy of the PL maximum does not follow the known temperature dependence of the InAs band gap also confirms that PL originates from radiative recombination between holes in the InSb insertion and electrons weakly confined by electrostatic interaction in the InAs barrier. The relatively small values of the PL peak width indicates, in our opinion, the formation of a QW in the structure since PL from QDs exhibits generally a significantly wider peak due to the inhomogeneous distribution of the dot sizes (see e.g. [2]).

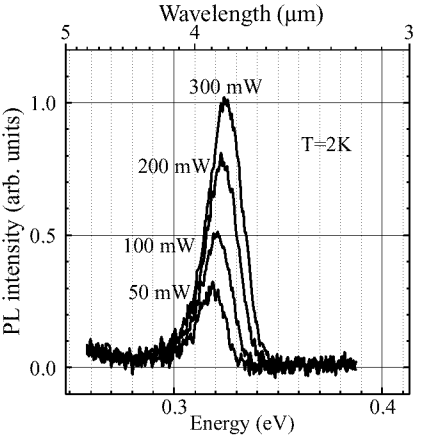

Fig. 2. PL spectra for different excitation densities.

In summary, we have grown a nanostructure containing an InSb QW in an InAs matrix,

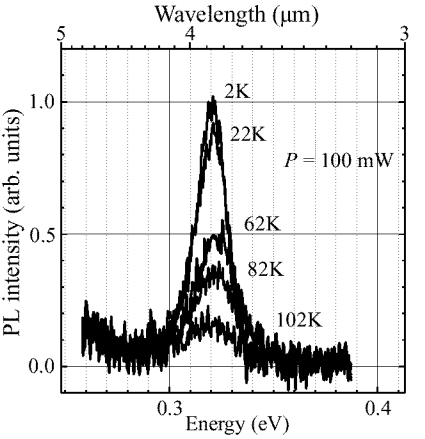

Fig. 3. Temperature dependence of PL spectra.

which objectively demonstrates the type-II band alignment. The PL emission ability of this structure near 4 μm is demonstrated. This work is the initial step in the fabrication and studies of InSb/InAs nanostructures and further structural and optical investigations are currently in progress.

Acknowledgements

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